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OPERATIONAL EXPERIENCE WITH THE GTS-LHC ION SOURCE AND FUTURE DEVELOPMENTS OF THE CERN ION INJECTOR

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Abstract

Since 2010 the GTS-LHC source delivers lead ions for heavy ion physics at the LHC. Several modifications allowed the improvement the source reliability and the beam stability. The attempts to improve the beam intensity were less successful. The different modifications and actual performance figures will be presented in this paper. In addition to the heavy ion physics program of the LHC new ion species will be requested for different experiments in the future. The fixed target experiment NA61 requires primary argon and xenon beams. And a future biomedical facility asks for light ions in the range helium to neon. Approaches to prepare these beams and to modify the ion injector towards a light ion front end are presented.

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In addition to the heavy ion physics program of the LHC new ion species will be requested for different experiments in the future. The fixed target experiment NA61 requires primary argon and xenon beams. And a future biomedical facility asks for light ions in the range helium to neon. Approaches to prepare these beams and to modify the ion injector towards a light ion front end are presented.

INTRODUCTION

The GTS-LHC source was installed and commissioned in 2005. It delivered the Lead ion beam needed for the commissioning of the heavy ion injector chain: Linac3 - Low Energy Ion Ring (LEIR) - Proton Synchotron (PS) – Super Proton Synchotron (SPS). For the very first setting up of LEIR also an oxygen ion beam was used.

In 2010 and 2011 the LHC used the lead beam for heavy ion collisions at a momentum of 1.38 A TeV/c. In parallel NA61 used the beam for fixed target physics [1].

HEAVY ION OPERATION

The GTS-LHC ECR Ion Source was built by CEA, Grenoble, and installed at Linac3 in 2005. It uses three warm electromagnet solenoids to generate a minimum B configuration, and a permanent magnet hexapole for radial plasma confinement. The source is injected with 14.5 GHz microwaves, typically using 10 Hz repetition cycles of 50 ms pulse length. Lead is introduced through a resistively heated micro-oven and mixed with oxygen gas. The source uses the afterglow technique to increase the intensity of high charge state ions for injection into the LEIR synchrotron, extracting Pb^{29+} with a voltage of 18.8 kV. More information can be found in [2]

The GTS-LHC source and Linac3 were running about 26 weeks in 2011. Most of the time was used for setting up the injector chain. 778 hours beam time was taken for physics. During the physics period a total of 45 hours were needed for two oven refills and 2.4 hours the source was down due to failures. Since then the oven refills could be optimized. Now it takes in average 8-10 hours from the stop of the source until a stable beam is available again.

For the year 2011 several improvements on the source were done:

- The gas injection feedback loop was sensitive to the microwaves injected into the source. This has been improved with a different gauge type (IMR265 by Pfeiffer) installed close to the gas injection valve that could be used for the feedback loop (see Figure 1). This eliminated the sensitivity to the microwave and in addition it smooths out any (fast) pressure fluctuations in the source.

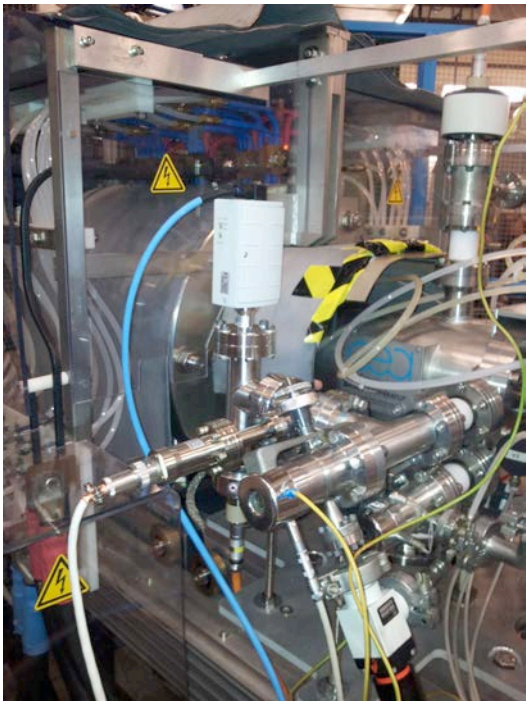

Figure 1: Gas injection with new gauge (in the center of the picture) for gas injection feedback loop.

- The electrical connection of the intermediate electrode failed regularly in previous years. The connection wire had a direct view of the beam, and the kapton insulation was eroded over some period which resulted in a short circuit. An additional insulation with a kapton tubing and a shielding with a wire mesh (braid) was made (see Figure 2), and inspection after the run showed no damage this time.

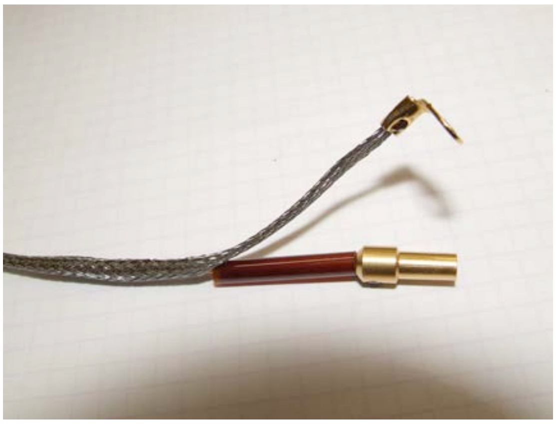

Figure 2: Modified electrical connection for the intermediate electrode.

To improve the amount of lead available from the source an attempt was made to fill the sample with liquid lead. But it turned out that for the operation a higher oven power was needed and that the output hole of the oven became clogged much faster with lead oxide (see Figure 3), actually leading to a reduction in lifetime. So this was discarded for the operation.

Figure 3: Oven tip clogged with lead and lead oxide.

The source delivered 80-130 eμA of Pb^{29+} out of the RFQ, which correspond to 20-22 eμA of Pb^{54+} at the end of the linear accelerator (after stripping). These are not record intensities as this time the source was tuned for stability.

When the source was commissioned the first time a plasma chamber made of aluminium was used. The beam intensity with this chamber was good but the beam stability over a long period was not acceptable. After a long period of operation some traces of damage were found inside the chamber. To avoid any problem during the physics run the chamber was replaced by a new one made of stainless steel. The performance was similar but the beam stability was noticeably improved. The only difference in the tuning of the source between aluminium and stainless steel chamber is the required microwave power. One needs roughly a factor three more power in the stainless steel chamber.

An explanation for the different beam stability could be the stiffness of the chamber. It was noticed that the aluminium chamber is less stiff and reacts on changes of the cooling water pressure and temperature with small changes in the source vacuum pressure (opening and closing leaks due to distortion of the chamber by the water temperature and pressure). These small leaks influence the ion production in the plasma. To test this hypothesis a stainless steel chamber coated on the inside with a thin layer of aluminium is in preparation.

The 18 GHz tests

Following the results presented in [2] some more tests were done to improve the source performance using a microwave frequency of 18 GHz. Almost no improvement of the intensity of the Pb^{29+} ion could be found. There are several possible explanations for this result:

- The low energy beam transport line (LEBT) following after the source cannot transport the complete beam and losses reduce the extracted beam intensity. If the beam is scraped before entering the Faraday cup higher extracted currents are not visible.
- Pb^{29+} is only a medium charge state. For higher charge states some higher beam currents for 18 GHz compared to 14.5 GHz could be seen, but for operation the particle current is the figure of merit (the beam is stripped at the end of the linear accelerator).
- One test gave a hint that the maximum available microwave power at 18 GHz (2.4kW) may not be sufficient for optimal beam production.

As no improvement could be found after several attempts, it was decided to convert the 18 GHz generator to a 14.5 GHz generator to have a hot spare for operation.

LIGHT IONS FOR THE FIXED TARGET PHYSICS

Another client of ion beams at CERN is the experiment NA61 (see Figure 4) which is situated in the North Area of the SPS. This fixed target experiment studies phase transitions in strongly interacting matter (quark-gluon plasma). Up to now protons, indium and lead primary beams were used. Beryllium was created as a secondary beam from a lead primary beam.

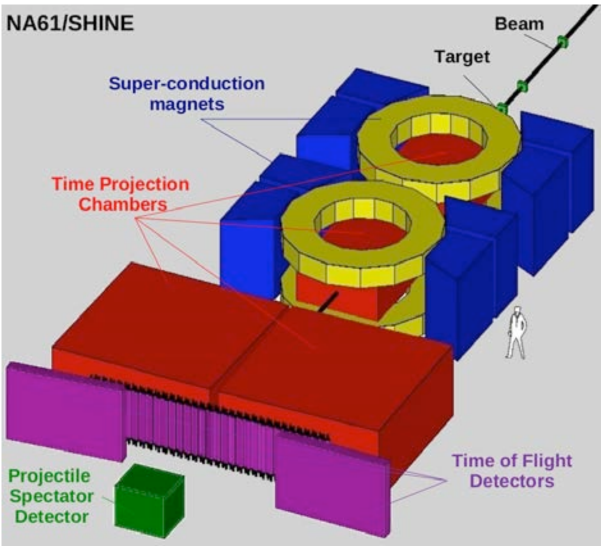

Figure 4: Scheme of the NA61 experiment.

Scaling the SPS energy and with different projectile ions the properties of the transition can be studied, and therefore argon and xenon were requested as primary beams.

In order to set up the injector chain with new ions, and make the physics run, more than 20 weeks of beam time is needed, and hence the source must also be quite stable over this period, testing the stability is one of the driving factors on the length of the required time to set up the source. Due to the limited time the source and Linac3 are available for tests, a collaboration with iThemba LABS in South Africa was signed. The advantage is that iThemba LABS has an identical source and the results gained there [3] can be used directly at the GTS-LHC source.

The argon beam will be studied at Linac3 in 2013.

A FUTURE BIOMEDICAL FACILITY

A meeting with potential users in June 2012 showed a big interest within the user community to have a dedicated facility for basic research related to hadron therapy for cancer. Light ions from protons up to neon at an energy of up to several 100 MeV/u are requested. These beams would mainly be used to irradiate cell cultures to study the biological effect of light ions onto cancer cells.

The main idea is to use the LEIR synchrotron which is part of the LHC ion injector chain, and would be able to deliver stacked, cooled and accelerated ions in the requested energy range. The ion beam for LHC is only required for part of the year, and even then only for studies, and during the LHC injection process, so Linac3 and LEIR would be available for such a biomedical facility during the rest of the time.

At the moment a study is under way to review the modifications needed in Linac3 and LEIR to be able to create, accelerate and extract light ions of the requested beam types, with the boundary condition that lead operation for LHC must not be perturbed, and switching from LHC lead operation, to medical ion operation should only take a few minutes.

For the light ion front end three options are under discussion.

1. An extension of Linac3 with a new source, a new RFQ and a switchyard to connect the new line with the present linear accelerator. The drawback is that some of the infrastructure work and installation can only be done when the present Linac3 does not run for heavy ion physics.
2. A complete new linear accelerator. A first estimate of these two options showed a very long schedule which is not very attractive for the user community that is already gaining momentum.
3. A commercial cyclotron with an external source.

Towards the end of this year a decision should be made based on schedule, budget and manpower on one of these options for further studies.

The source for this project has to deliver high currents of the requested ions for periods of several days to some weeks with a high stability and reliability. The type of source is not yet chosen, but for first estimations of the beam performance a commercial ECR source was used.

The source extraction voltage affects the current that can be extracted from the source and the beam transport until the RFQ. But a too high injection energy into the RFQ makes this device very long. Several injection energies were studied and 5 keV/u and 7.5 keV/u were found to be a good compromise between high source extraction voltage and the length of the RFQ. Detailed studies will concentrate on these values.

CONCLUSIONS

The GTS-LHC source delivered successfully Lead ions for the heavy ion physics at the LHC and for the fixed target experiment NA61. Several modifications improved the reliability of the source and lead to a better beam stability and higher up time for physics. As next the beam intensity has to be improved, but without jeopardizing the stability.

New ion beams have to be studied and to be made available for the users.

Future machine extensions could extend the catalogue of available ion species for a new user community.

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